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ELECTRICAL PROPERTIES OF INDIAN MICA
I—POWER FACTOR

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ABSTRACT. In this paper, the results of measurements of power factor of a large number of samples of mica of different qualities available in different parts of India are reported and their suitability as electrical insulants in electrical industry is discussed.

INTRODUCTION

Mica occupies a unique position as an electrical insulant amongst the raw materials for the manufacture of electrical apparatus. Owing to many desirable physical and chemical properties which it possesses, its superiority over other solid dielectrics is but little doubted. In fact, mica, for its exceptional insulating properties, is considered an indispensable element for the growth of electrical industry, especially when a flexible insulating medium to sustain very high electrical, mechanical and thermal stresses is necessary, although there are limitations to the size of pieces in which it is available.

This valuable electrical insulation is a crystalline mineral, which occurs in various forms and is very widely dispersed throughout the various terrestrial strata. But it is relatively in few localities that the mica used in electrical industry is obtained in sufficiently large dimensions and quantities to be of any commercial importance. Such localities lie in India, Canada, the United States, Guatemala, Argentina, Brazil, Madagascar, Tanganyika, South Africa, Russia, Northern Australia and Norway. But amongst these countries, India is the greatest producer of good quality sheet mica and at present provides more than 80 per cent of the world's demand of this important and unique mineral. With the growing enterprise for the manufacture of electrical apparatus in India, it is realised that the electrical properties of mica available in the different localities of this vast country should be studied with a view to ascertaining their suitability for different service requirements.

It is proposed to study in a series of investigations those electrical properties, *viz.*, power factor, dielectric constant (or permitivity), dielectric strength and resistivity, which are of importance to the electrical industry. It is also interesting to enquire how these properties are influenced by variations of temperature, humidity and frequency. Much work has, however, been done in the past by a large number of foreign workers in this direction. The results of the early investigators show wide variations from one another due to many experimental difficulties. But the recent works of Dannatt and Goodall (1930), of Lewis, Hall and Caldwal (1931), of Hartshorn and Ruston (1939), and of Hackett and Thomas (1941), are very reliable and supply us with much useful information regarding these properties of mica in general. Little attempts have, however, been made to carry out a comparison of the properties of different kinds of mica produced in different parts of India. Such information is expected to be of great importance to the development of electrical industries in this country. In the present paper are reported the results of measurements of power factor of Indian mica of different kinds available through the Geological Survey of India.

THE MICA OF ELECTRICAL INDUSTRY

To the mineralogists, the following eight different varieties of mica are so far known. They are—

(1) Muscovite or potassium mica,
(2) Paragonite or sodium mica,
(3) Zinwaldite or lithium-iron mica,
(4) Lepidolite or lithium mica,
(5) Phlogopite or magnesium mica,
(6) Biotite or magnesium-iron mica,
(7) Lepidomelane or ferric-iron mica,
(8) Roscoelite or vanadium mica.

These different varieties are classified into two principal groups, namely, the granitic group and the pyroxenic group, according to the nature of their geological formation. The first four varieties belong to the granitic group while the last four, to the pyroxenic group. The members of each group are different in chemical composition but they may, in general, be regarded as ortho-silicates of aluminium with alkali metals (potassium, sodium or lithium), magnesium, iron and fluorine present in varying amounts. They are characterised by perfect basal cleavage, yielding readily very thin, strong and flexible splittings. Amongst these varieties, only the muscovite and the phlogopite mica find applications as electrical insulants and represent, therefore, the mica of electrical industry. They are available in abundance and in suitable sizes for commercial purposes.

Of the world's known deposits of mica, muscovite occurs in a larger number of countries than phlogopite. In fact, commercially important deposits of muscovite mica are found in India, United States, Russia, Norway, Argentina, Brazil, Tanganyika and Guatemala, while those of phlogopite mica only in Canada and Madagascar. There are, however, many other countries in which either of these two varieties or both are found to occur but they do not hold out any commercial prospect.

The approximate chemical formula of muscovite is given as $KH_2Al_3(SiO_4)_3$ while that of phlogopite as $KH(MgF)_3.Mg_3Al(SiO_4)_3$. Besides being almost chemically inert, these two varieties of mica possess many useful mechanical properties, such as a high degree of flexibility, elasticity, toughness, hardness and ability to withstand heat, for which they are often preferred to other solid dielectrics for use in electrical industry. They have, however, important differences, which greatly affect their suitability for particular conditions of service. In fact, phlogopite is distinctly inferior to muscovite as regards rigidity, hardness, toughness and elasticity and does not also split so readily. But it is generally more flexible than muscovite and can withstand higher temperatures. The surface of individual splittings of muscovite is smooth whereas the splittings of phlogopite have a fine crinkled surface, which is useful for certain purposes. But muscovite mica, because of its superior electrical and many mechanical properties, is more in demand than phlogopite in electrical industry.

Almost all the mica deposits in India belong to the muscovite variety with biotite in frequent association with it, the solitary exception so far known, being a small occurrence of phlogopite in the State of Travancore in Madras. The economic selection of the correct type of Indian mica for specific engineering purposes requires, however, a knowledge of their occurrence and classification, besides an acquaintance with their electrical properties.

OCCURRENCE OF MICA IN INDIA

There are many localities in India where muscovite mica occurs in the granitic pegmatites associated with mica schists. Bihar, Madras and Rajputana are at present the three important mica-producing centres. Amongst them, Bihar is the largest and produces about more than 75 per cent of the total production of mica in India. Madras comes next in importance while the mica deposits in Rajputana have only recently been commercially exploited. In addition to these three principal centres of mica deposits occurrences of mica have also been recorded in other parts of India.

The important mica centres in Bihar lie in the districts of Hazaribagh. Gaya and Monghyr. Hazaribagh contains the best mica reserve in India. Kodarma in this district is the largest centre of block mica while Giridih claims to be the largest centre for the finest class of mica splittings. Mica deposits in Manbhum and Bhagalpur districts have been of late commercially exploited. There are also occurrences of mica in Singhbhum, Palamau and Santal Parganas.

It may be mentioned here that the present Bihar mica field was included within the province of Bengal till 1912. Mica produced in this belt was therefore called and in fact is still known commercially as Bengal mica. At present Bengal proper does not produce any mica of commercial value, only a scanty occurrence of it having been recorded in the district of Bankura some years ago.

The chief mica deposits in Madras occur in the district of Nellore. There are a large number of mica mines in this area. Deposits in other districts, *viz.*, Nilgiris, Coimbatore and Malabar, are not commercially very important. Mica occurs also in the States of Travancore and Mysore. The most important centre of mica mining in Travancore is Eraniel. Travancore mica is principally phlogopite. Mica-bearing rocks in Mysore lie in the districts of Hassan, Mysore and Sringeri Jahgir. An occurrence of mica is also recorded in Coorg.

The third important mica deposit in India occurs in Rajputana in Central India. The major part of this deposit falls within the British territory of Ajmere-Merwara. There are however many States in Rajputana, namely, Jaipur, Tonk, Kishengarh, Sirohi, Udaipur, Shahpura and Jodhpur, where deposits of good quality mica have been found and in some cases commercially exploited. In addition to Rajputana, there are a few other States in Central India, such as Tehri, Gwalior, Jhabua, Rewah and Jashpur, where occurrences of mica have been also reported.

Mica deposits in the Central Provinces occur in the districts of Balaghat and Bilashpur, and also in Nandgaon and Bastar States. But they do not appear promising commercially. The Patiala State and the Kangra district in the Punjab as well as Garhwal in the United Provinces contain also good deposits of mica. In the newly-formed province of Orissa, occurrences of mica have been found in the districts of Sambalpur and Ganjam and also in the States of Mayurbhanj, Bamra, Ganpur and Bonai.

It is next of importance to enquire into the classification of the mica produced in the aforesaid localities.

CLASSIFICATION OF INDIAN MICA

Indian mica may in general be designated after the name of the province or locality of its occurrence. It is however usual to classify the muscovite mica, which is India's principal production, into two main types according to its colour, namely, ruby muscovite and green muscovite. The colour of ruby muscovite varies usually from light brownish-red in thin splittings to dark ruby-red in thick plates. Green muscovite varies from green to greenish-brown and sometimes to dark in very thick plates. Besides these two types, white and brown muscovite micas are also found in certain localities. Clear muscovite mica of any kind is, however, colourless in very thin splittings. The special feature of Bihar mica is its characteristic ruby colour. Green, brown and white micas are also occasionally found in Bihar. Madras mica is characteristically of the green muscovite type with only one exception, namely, that of Kalichedu mine, where pale ruby type is found. Rajputana mica belongs to both ruby and green types.

According to quality, each type of muscovite mica may be further subdivided into various kinds, such as clear, stained, spotted, slightly stained, heavily stained, slightly spotted, heavily spotted, stained and spotted, etc., depending upon the presence of impurities and inclusion in it. This method of classification is also adopted in trade.

In the present investigation different samples of mica of different kinds, which could be secured from different localities, have been tested for their power factor, whose knowledge is of fundamental importance for their use in electrical industry.

POWER FACTOR

It is well known that a perfect dielectric has only one electrical property, namely, that of specific inductive capacity or permitivity. When a sinusoidal voltage is impressed, the current that flows through it, leads the voltage in phase by $\pi/2$ radians. But in none of the solid dielectrics this ideal phase relationship between their current and voltage is satisfied. In fact, the phase difference between them is found to be slightly less than $\pi/2$. This defect from the ideal phase relationship is known as the "loss angle" of a dielectric while the sine of this angle gives a measure of its power factor. Thus if the loss angle of the dielectric is denoted by δ, its power factor is given by sin δ. When δ is very small, sin δ may also be replaced by tan δ. A knowledge of the power factor gives at once an idea of the power loss in the dielectric. The larger the value of power factor, the greater is the magnitude of the dielectric loss. Hence the importance of power factor measurements of dielectrics for ascertaining their usefulness in electrical industry is evident.

The power factor or the dielectric loss of mica, available in different parts of the world, has been the subject of a very large number of investigations. As early as 1912 Symons Walker (1912) made an attempt to estimate its value for different kinds of mica. Since then the experimental technique and methods of its measurement have been much improved and very reliable data of its value are available. Amongst the several investigators, Dye and Hartshorn (1924) estimated the power factor of the muscovite variety of Indian mica known as Bengal ruby, Madras green and Madras brown micas of different qualities, namely, clear, stained and spotted. But they used a method which does not admit of great accuracy. Using a Schering bridge, Dannatt and Goodall (1930) obtained very accurate data of power factor of ruby and green varieties of clear muscovite mica as well as of amber mica and studied the effects of temperature, stress and frequency on their power factor over a range covering the working conditions met with in electrical engineering practice. Unfortunately, these authors do not explicitly mention the geographical origin of the samples of mica tested by them. But it is very probable that some of them were taken from India. Lewis, Hall and Caldwell (1931) carried out power factor test on a large number of samples of micas, fairly representative of the major sources of the world's supply of mica. A few samples of clear and stained muscovite micas from India were also included in their list. The method used by these authors for evaluating the value of power factor was similar in principle to that employed by Dye and Hartshorn. Very recently Hartshorn and Rushton (1939), have investigated the power losses in mica subjected to the action of an alternating voltage at frequencies 50 to 4,000 cycles per second. The variations of the losses with moisture content, temperature, frequency, voltage and thickness have been also studied in detail in the case of typical samples of clear ruby mica.

From above it is evident that an extensive study of the power factor of mica available in different localities in India, which is the world's largest source of mica supply, is still wanting. To obtain the data of power factor within reasonable accuracy, a proper choice of the method of measurement is essential in addition to the careful preparation of the test condenser.

METHOD OF MEASUREMENT

A condenser is formed with the dielectric under test as the medium between its electrodes and its power factor is then evaluated. Several methods have been devised for the purpose. Earlier workers used wattmeter methods which suffered from errors inherent in such deflectional methods. They were not suitable for measurements at high voltages and the range of frequencies at which such instruments could be used was also very limited. Later on, several investigators calculated the value of power factor from measurements of the capacitance and the equivalent shunt or series resistance of the test condenser at a known frequency by using several bridge methods. Although the capacitance could be measured with considerable precision, there was great uncertainty in determining the equivalent shunt or series resistance because of the errors due to residuals in a bridge network. To avoid these errors, a resonance-capacitance method has also been used by a number of workers. Very recently, Hartshorn and Ward (1936) have devised a novel and ingenious method for the measurement of power factor of insulating materials over a wide range of radio-frequencies. This method employs capacitance-variation in a tuned circuit with a thermionic voltmeter as a detector of resonance. A cylindrical condenser of very small range of capacity whose variation follows a simple linear law is used to secure sharpness of resonance. Power factor of the test condenser and hence of the insulating material is obtained as a ratio of two capacitance readings. Thus frequency is not involved in the calculation of power factor. It is this property which enables the method to be employed over a wide range of frequencies. The errors due to residual inductance and resistance even at the highest frequency are eliminated by a careful design of the apparatus and by following a careful procedure in making the measurements.

A simple but a very accurate bridge method of measuring power factor when a precision condenser of negligible or known dielectric loss is available is that devised by Schering in 1920. Since then it has been considerably modified by several investigators to use it over wide ranges of voltage and frequency but is still known as the Schering bridge. In fact, it is used widely at present for accurate measurements of power factor. Like all bridge methods, it consists essentially of a Wheatstone network. The source of e.m f. is an alternating one either at power or any desired higher frequency. The nature of detector employed depends upon the frequency at which measurement is to be made, Usually, a vibration galvanometer is used directly at power frequency while a headphone at higher frequencies up to about 1000 cycles per second. Cathode-ray and heterodyne null detectors are employed at still higher frequencies and are more sensitive null detectors than others. The electrostatic screening and the Wagner-earthing are the two notable features of the Schering bridge. The former shields the bridge from the influence of external electrostatic fields while the latter eliminates the errors due to electrostatic coupling between various arms of the bridge and due to earth capacities of the various parts of the apparatus.

Many commercial forms of the modified Schering bridge are at present available. One such commercial bridge manufactured by Messrs. British Physical Laboratories, Ltd., London, which claims a high degree of precision for capacitance and power factor measurements, has been used in the present investigation.

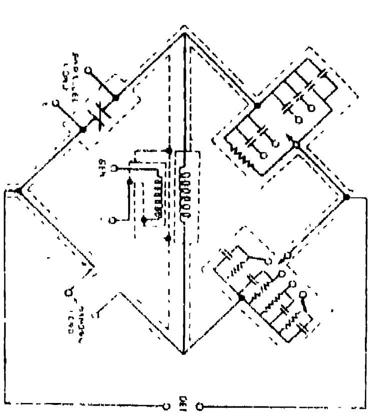

FIG. 1

The general arrangement of the bridge is shown in Fig. 1. The ratio arm across which the power factor condenser is connected has a value of 30,000 ohms. The other ratio arm consists of four independent resistance units of values 30,000, 3,000, 300 and 30 ohms. These resistances have suitable mica condensers in parallel in order to give a constant value of RC so that the accuracy of power factor measurement may be obtained over the entire range. All the resistances are completely non-inductive and have an accuracy of 0.01%. The dial connecting the two ratio arms indicates multiplying factors of values 1, 10, 100 and 1000. A high-precision variable air condenser which is employed as a standard of capacity forms one of the two remaining bridge arms. This condenser is designed to give a constant power factor with capacity and hence it has a constant loss with frequency. Its dial consists of a worm drive having no back-lash and its scale is direct reading in micro-microFarads from 0 to 1140. Using the multiplying factors, capacities up to 1.14 F can be measured in four ranges. The capacity dial is accurate within $\pm 0.1\%$. The power factor standard consists of a variable condenser having a logarithmic change of capacity with the angle of rotation. Its dial is also direct reading in % from 0 to 0.06 with an accuracy of $\pm 0.05\%$. The logarithmic characteristic of the scale enables to obtain good reading near the zero point. The bridge can be used on 50 to 10,000 cycles frequency range. The calibration of the power factor dials corresponds to one kilo-cycle.

Supply to the bridge is taken through a transformer from a beat frequency oscillator fed from an A.C. supply of 220 V. at 50 cycles and capable of giving a frequency range of 25 to 10,000 cycles per second within an accuracy of $\pm 1\%$.

The balance indicator is a General Radio cathode-ray null detector of the visual type which can be used with bridges operating at any frequency between 25 cycles and 20 kilo-cycles. It employs a tuned degenerative amplifier which is entirely free from any electromagnetic or electrostatic pick up and does not itself radiate any appreciable electromagnetic field. One of its advantages is its ability to indicate, separately, the effect of adjusting the resistive or reactive controls of the bridge. It indicates also whether one of these controls, selected as desired, is off-balance in a positive or a negative direction. The bridge output is applied to the vertical deflecting plates of the cathode-ray tube through the amplifier while the bridge generator voltage is applied to its horizontal plates through an adjustable phase-shifting network. An elliptical pattern is produced on the screen when the bridge is out of balance. But on balancing, this is reduced to a horizontal straight line. The observable sensitivity of the detector is about 200-300 microvolts at 1000 cycles.

As indicated by dotted lines in Fig. 1, sufficient care has been taken to shield completely each arm of the bridge including the condensers, resistances, connecting leads, etc. The two windings of the transformer are electrostatically shielded from one another while the transformer itself is contained in a cast-iron box which gives complete magnetic shielding against external fields.

PREPARATION OF TEST CONDENSER

It has been mentioned in the previous section that for ascertaining the power factor of a dielectric, a test condenser is prepared by inserting the sample between two electrodes. But the value of power factor is liable to be greatly affected by the nature of such electrodes because of the contact resistance and capacitance of measurable amounts that exist in many cases. A proper choice of electrodes which would make intimate contact with the test sample is, therefore, very essential.

A considerable amount of information regarding the properties of electrode contacts and their effects on the measurements of dielectric properties are now available. Such information obtained previous to 1924 was summarised by Hartshorn in 1926. Churcher (1929) and his co-workers on behalf of the Electrical Research Association undertook a detailed investigation into contact effects between electrodes and dielectrics and recommended electrodes of mercury or of graphite (in the form of Aquadag) backed with metal plates for obtaining best results. It was also found that in certain cases graphite backed with mercury gave better contact than that obtained with mercury alone. Later on, Hartshorn and Ward at the National Physical Laboratory as well as Sharpe and O'Kane at the Applied Electricity Laboratory of Liverpool University found independently that although the results obtained in the above investigation were satisfactory for measurements at power frequencies, errors in measurements at higher frequencies could not be explained on the basis of the then knowledge of electrode contact. This led them to undertake a further investigation into the subject and they published their results (Hartshorn, Ward, Sharpe and O'Kane, 1934) jointly in 1934. They are of opinion that for general purposes mercury electrodes are the most satisfactory for measurements of permitivity and power factor of insulating materials in sheet form, although a film of graphite between mercury and test sample may improve the contact as previously noted by Churcher and his co-workers. They have further found that thin tin-foil applied with a trace of vaseline as an adhesive is a good substitute for mercury. Graphite electrodes backed with metal plates are easy to apply but should be employed with sufficient care at audio frequencies and not at all at radio frequencies.

For measurements of permitivity and power factor of mica, several of the early investigators prepared the test condenser by simply pressing two sheets of tin foil into contact with the sample, one on either side of it, without the use of any adhesive. There was, therefore, much uncertainty in securing intimate contact between the sample and the electrodes. Others used electrodes of mercury. Unless special precautions are taken, air bubbles are apt to form on the surface of the sample and so vitiate results. It may be mentioned here that the usual method of floating the test specimen on mercury with an upper mercury electrode is impracticable in the case of mica because of the thinness and flexibility of the samples. Another method consisted in inserting the sample into the gap of a parallel-plate air condenser of known dimensions. This is also not free from many serious objections. Dye and Hartshorn (1924) used both the air gap and the mercury electrode methods. In the latter case, the mercury electrodes were contained in ebonite dams and found to be very satisfactory. Dannatt and Goodall (1930) employed electrodes of mercury as well as of graphite in the form of Aquadag. They found that much of the trouble due to uncertainty of contact between the sample and the electrodes was due to a film of contamination present on the surface of mica specimen. Considerable improvement was effected by washing the surfaces with methylated ether just before the application of electrodes. In the case of graphite electrodes this method of treatment gave very satisfactory results. But for mercury electrodes, more elaborate precautions were necessary in order to obtain consistent results. Perfectly clean mercury had to be used and a somewhat tedious routine of washing surfaces, first with methylated spirit and then with methylated ether and finally drying them at 30°-40°C, was evolved. In the opinion of these authors, careful use of graphite electrodes gives accurate and consistent results. Lewis and his co-workers. (Lewis Hall and Caldwell, 1931) used tin foils as electrodes and linseed oil as an adhesive.

In preparing the test condenser in the present investigation due considerations were given to the fact that, since a large number of samples had to be tested, the electrodes should be so chosen that they would admit of easy manipulation without sacrificing accuracy. From this point of view it was decided to use thin tin foils as electrodes with a trace of linseed oil as an adhesive. Extreme care was taken to prepare a test-piece before applying the electrodes to it. From each block of a given sample of mica under test, several thin pieces approximately 2 cm. by 1 cm., were cut or split. They were then carefully examined and any loose layer, if present, was removed from them. The average thickness of each piece was measured with the help of a dial gauge. To minimise the effect of contact resistance, pieces of thickness less than 2 mils were rejected. Before fixing the electrodes the surfaces of each piece were first carefully cleaned with methylated spirit and linseed oil spread over them. With a clean and dry cloth, the oil was wiped out from each face. The slight trace of oil that still remained over the faces helped the thin tin foils to adhere to them. Thus the presence of any air pocket between the surfaces of the test piece and the electrodes was avoided. A somswhat similar process was adopted by Lewis, Hall and Caldwell, who found that the effect of introducing two films of oil of unknown thickness into the test condenser is not very appreciable on the values of power factor.

EXPERIMENTAL PROCEDURE

The method of substitution was employed for measurements which were made at the room temperature varying from about 30°C to 36°C on different days during the period of investigation. A standard air condenser was connected to the unknown or fourth arm of the bridge. The ratio of the resistances in the ratio arms was kept fixed at a definite value throughout the operations. Balance was obtained once with the bridge standard condenser alone in the third arm and then with the test condenser connected across it. It is well known that under the above conditions of balance, we have,

firstly, $$C/C_S = R_2/R_1 \qquad \ldots (1)$$

and $$\phi-\phi_S = \phi_2-\phi_1, \qquad \ldots (2)$$

and secondly, $$C/C'_S + C_T = R_2/R_1 \qquad \ldots (3)$$

and $$\phi-\phi_T = \phi'_2-\phi_1, \qquad \ldots (4)$$

where C and ϕ = capacity and power factor of the standard air condenser respectively ;

C_S and C'_S = capacity of the bridge standard condenser before and after substitution, respectively ;

C_T = capacity of the test condenser ;

ϕ_S = constant power factor of the bridge standard condenser ;

ϕ_T = power factor of the test condenser ;

$\phi_2-\phi_1$ and $\phi'_2-\phi_1$ = difference of power factor of the balancing arms of the bridge, before and after substitution, respectively ;

and R_2/R_1 = ratio of resistances in the ratio arms of the bridge.

From equations (1) and (3) and from (2) and (4), we have

$$C_T = C_S - C'_S \qquad \ldots (5)$$

and $$\phi_T - \phi_S = \phi_2 - \phi'_2 \qquad \ldots (6)$$

But assuming ϕ_S to be negligible in comparison to ϕ_T, we get

$$\phi_T = \phi_2 - \phi'_2. \qquad \ldots (7)$$

It is evident from equations (5) and (7) that the capacity and power factor of the test condenser can be obtained directly from the difference of capacity and power factor dial readings of the bridge before and after substitution.

In actual practice, the ratio of the resistances in the ratio arms of the bridge was kept fixed at unity and the standard air condenser was given a suitable value which was kept unaltered during the two operations. Hence C and ϕ were maintained also constant. Balance under each condition was obtained by adjusting the bridge standard condenser as well as the power factor standard condenser at the maximum input of the bridge and at the maximum gain of the detector. After each balance, the capacity and power factor dial readings were noted.

From each sample of mica, several test condensers were prepared as described already and the values of their factor were measured on different days. The power factor of each test condenser was found to be substantially constant. The slight variations, wherever noticed, may be attributed to variations in the room temperature and atmospheric humidity. Incidentally, it may be mentioned here that the effect of humidity on power factor while considered to be too small by Dannatt and Goodall (1930) was thought to be of appreciable magnitude by Hartshorn and Ruston (1939). In the present measurements, we have not, however, made any careful study to ascertain any correlation between power factor and humidity but hope to undertake this investigation in future.

A few test readings were also taken with the bridge in order to check the experimental accuracy of the measuring system. We know that if r is the small effective series resistance in the condenser, the power factor is given, by $r\omega C$. Using a standard condenser and non-inductive resistances of known values, the change in power factor could thus be calculated very readily. This change was also ascertained from the difference of the power factor dial readings of the bridge. The deviation in each case was found to be within $\pm 4.5\%$. This order of accuracy may be considered fairly tolerable in the present series of measurements which aim mainly at a comparative study of power factor of the different kinds of mica available in the different parts of this country. It may be mentioned further that the series resistances used with the standard condenser were assumed to be truly non-inductive. Presence of any inductance would, however, increase the effective capacity. But this effect, if present at all, can legitimately be overlooked at the frequency of one kilo-cycle per second. This is borne out by the observed data which are in all cases less than their calculated values. The presence of any series inductance effect would have influenced the observed values in the opposite sense. The effect due to the presence of self-capacity of non-inductive resistances is also negligible at the above frequency.

EXPERIMENTAL RESULTS

Tables I-IX contain the data of power factor of mica obtained from different parts of India. In Column 1 is given the designation adopted by the Geological Survey of India for each kind and quality of mica as well as the name of the

TABLE I
Bihar Mica
Bengal Ruby Mica

Designation and colour	Quality	Average thickness (in mils)	Number of samples tested	Power factor Spread %	Power factor Average %
Ruby Red ...	Clear ...	4	6	0.0092—0.0106	0.0102
		6	6	0.0098—0.0110	0.0104
		8	6	0.0094—0.0112	0.0106
C—Red ...	Stained ...	4	6	0.0103—0.0238	0.0152
		6	6	0.0101—0.0259	0.0186
		8	8	0.0109—0.0257	0.0176
D—Red ...	Stained ...	5	6	0.0192—0.0300	0.0262
		7	9	0.0182—0.0319	0.0251
		9	7	0.0228—0.0267	0.0249
A—Red ...	Stained and slightly spotted.	4	7	0.0116—0.0192	0.0143
		6	8	0.0105—0.0205	0.0152
		8	10	0.0107—0.0210	0.0146
F—Red ...	Stained and slightly spotted.	4	7	0.0107—0.0203	0.0142
		6	8	0.0140—0.0185	0.0162
		8	7	0.0102—0.0232	0.0128

TABLE II
Madras Mica

Designation and colour	Quality	Average thickness (in mils)	Number of samples tested	Power factor Spread %	Power factor Average %
Madras Green ...	Clear ...	4	6	0.0102—0.0122	0.0114
		6	6	0.0104—0.0124	0.0116
		8	6	0.0102—0.0126	0.0118
C—Green ...	Stained ...	5	6	0.0160—0.0313	0.0229
		7	6	0.0151—0.0316	0.0235
		9	7	0.0174—0.0300	0.0258
D—Green ...	Stained ...	5	8	0.0255—0.0384	0.0320
		7	8	0.0250—0.0400	0.0308
		9	6	0.0278—0.0341	0.0309
A—Green ...	Stained and slightly spotted	6	7	0.0232—0.0394	0.0288
		9	8	0.0203—0.0404	0.0274
		12	10	0.0189—0.0382	0.0307
F—Green ...	Stained and slightly spotted.	4	8	0.0112—0.0174	0.0137
		6	7	0.0120—0.0171	0.0146
		8	7	0.0112—0.0177	0.0158
M 177—Green (Palamani Mines, Nellore).	Stained and spotted.	3	5	0.0297—0.0357	0.0318
		5	6	0.0282—0.0362	0.0320
		7	6	0.0265—0.0366	0.0319
M 242—Green (Kandali Mine, Nellore).	Slightly stained with black metallic spots.	3	6	0.0141—0.0272	0.0202
		5	6	0.0152—0.0263	0.0200
		7	6	0.0134—0.0265	0.0194
M 236—Green (Kalichedu Mining Co., Nellore).	Stained and slightly spotted.	4	5	0.0174—0.0188	0.0183
		6	5	0.0135—0.0218	0.0191
		8	6	0.0132—0.0234	0.0182

TABLE III

Rajputana Mica

Designation and colour	Quality	Average thickness (in mils)	Number of samples tested	Power factor Spread %	Power factor Average %
0.273—Green (Jaitaram district, Jaipur).	Slightly stained.	3 5 7	5 6 5	0.0143—0.0170 0.0147—0.0171 0.0153—0.0173	0.0170 0.0165 0.0167
6552—Green (Jaipur).	Stained with black metallic spots.	4 6 8	5 7 7	0.0192—0.0219 0.0175—0.0233 0.0159—0.0377	0.0205 0.0208 0.0227
N756—Green (Tehri, Central India).	Slightly stained with black metallic spots.	4 6 8	5 6 6	0.0183—0.0192 0.0181—0.0191 0.0178—0.0198	0.0186 0.0185 0.0187
K162—Green (Daulatapura, Kishengarh).	Stained with black metallic spots.	4 6 8	5 5 6	0.0189—0.0285 0.0190—0.0281 0.0177—0.0328	0.0220 0.0225 0.0234
L333—Red (Udaipur).	Stained ...	3 5 7	7 5 5	0.0151—0.0199 0.0153—0.0198 0.0158—0.0186	0.0174 0.0172 0.0171
N758—Red (Dudpura near Beawar).	Stained and slightly spotted.	3 5 7	5 5 5	0.0143—0.0247 0.0140—0.0280 0.0151—0.0244	0.0188 0.0194 0.0193
N759—Red (Shahpura).	Stained with metallic spots.	4 6 8	7 6 7	0.0172—0.0240 0.0166—0.0226 0.0163—0.0245	0.0208 0.0205 0.0206

TABLE IV

Travancore Mica

Designation and colour	Quality	Average thickness (in mils)	Number of samples tested	Power factor Spread %	Power factor Average %
M 624—Red	Stained and spotted.	3 5 8	5 5 6	0.0278—0.0379 0.0283—0.0386 0.0202—0.0387	0.0329 0.0342 0.0318
L 999—Red (Tippermalai Mines).	Heavily stained and spotted.	3 5 7	5 7 7	0.0558—0.0886 0.0428—0.0884 0.0422—0.1010	0.0731 0.0750 0.0772
R 41—Red	Stained and heavily spotted.	3 4 6	5 6 6	0.0413—0.0833 0.0420—0.0962 0.0366—0.0956	0.0731 0.0735 0.0728
M 25—Red	Heavily stained (Phlogopite).	4 6 8	7 7 8	0.0496—0.1150 0.0494—0.1142 0.0522—0.1082	0.0800 0.0813 0.0829

TABLE V

Mysore Mica

Designation and colour	Quality	Average thickness (in mils)	Number of samples tested	Power factor	
				Spread %	Average %
M 620—Green	Clear	3	6	0.0103—0.0164	0.0114
		4	6	0.0102—0.0177	0.0119
		5	8	0.0108—0.0181	0.0118

TABLE VI

Orissa Mica

Designation and colour	Quality	Average thickness (in mils)	Number of samples tested	Power factor	
				Spread %	Average %
M 894—Red (Sambalpur)	Stained	3	5	0.0142—0.0245	0.0197
		5	6	0.0136—0.0261	0.0205
		7	6	0.0132—0.0264	0.0207

TABLE VII

U. P. Mica

Designation and colour	Quality	Average thickness (in mils)	Number of samples tested	Power factor	
				Spread %	Average %
I 581—Green (Garhwal).	Clear	3	5	0.0307—0.0537	0.0421
		5	5	0.0387—0.0566	0.0473
		7	6	0.0245—0.0761	0.0429

TABLE VIII

Punjab Mica

Designation and colour	Quality	Average thickness (in mils)	Number of samples tested	Power factor	
				Spread %	Average %
I 306—Red (North of Patiala)	Stained and slightly spotted.	4	8	0.0204—0.0386	0.9094
		6	8	0.0226—0.0365	0.2024
		8	10	0.0162—0.0553	0.0291

TABLE IX

Summary of Results

Source	Designation and colour	Kind or quality	Power factor	
			Average %	Spread %
Bihar	Bengal Ruby	Clear	0.0104	0.0092—0.0112
	C—Red	Stained	0.0173	0.0101—0.0259
	D—Red	Stained	0.0252	0.0182—0.0319
	A—Red	Stained & slightly spotted	0.0147	0.0105—0.0210
	F—Red	Stained & slightly spotted	0.0144	0.0102—0.0232
Madras	Muscovite Green.	Clear	0.0116	0.0102—0.0126
	C—Green	Stained	0.0241	0.0151—0.0316
	D—Green	Stained	0.0313	0.0250—0.0400
	A—Green	Stained & slightly spotted	0.0294	0.0189—0.0460
	F—Green	Stained & slightly spotted	0.0144	0.0112—0.0177
	M177—Green	Stained and spotted	0.0319	0.0265—0.0366
	M242—Green	Slightly stained with black metallic spots.	0.0198	0.0134—0.0272
	M236—Green	Stained & slightly spotted	0.0187	0.0132—0.0234
Rajputana	0273—Green	Slightly stained	0.0165	0.0143—0.0173
	N756—Green	Slightly stained with black metallic spots.	0.0186	0.0178—0.0198
	6552—Green	Stained with black metallic spots	0.0216	0.0159—0.0377
	K162—Green	Stained with black metallic spots	0.0227	0.0177—0.0328
	L333—Red	Stained	0.0172	0.0151—0.0190
	N758 Red	Stained and slightly spotted	0.0192	0.0140—0.0280
	N759 Red	Stained with metallic spots	0.0206	0.0163—0.0245
Travancore	M624—Red	Stained and spotted	0.0329	0.0202—0.0387
	R41—Red	Stained and heavily spotted	0.0732	0.0366—0.0962
	L999—Red	Heavily stained and spotted	0.0752	0.0422—0.1010
	M25—Red	Phlogopite, heavily stained	0.0815	0.0494—0.1150
Mysore	M620—Green	Clear	0.0118	0.0102—0.0181
Orissa	M894—Red	Stained	0.0203	0.0132—0.0264
U.P.	1581—Green	Clear	0.0440	0.0245—0.0761
Punjab	1306—Red	Stained and slightly spotted	0.0293	0.0162—0.0533

particular locality or mine of its occurrence contained within parentheses. It has not been possible to supply the latter information in every case. Column 2 gives the quality of each kind of mica tested. To carry out the test, the samples were first grouped into lots according to their thickness. The average thickness of the samples of a particular lot and the number of samples included in it, as well as the data of power factors spread and of average power factors of each such lot are given in columns 3, 4, 5 and 6 respectively. The power factor data have been expressed in percentage.

Finally, in Table IX are collected together for comparison the data of power factor obtained from measurements on the different samples, irrespective of their thickness, for each kind or quality of mica tested during the present investigation. It may be noted that excepting one quality of phlogophite mica obtained from Travancore, the others belong to the muscovite variety.

DISCUSSION

From Table IX, it is easily seen that the average power factor of clear muscovite mica, excepting that obtained from the United Provinces, is very small although the green variety of both Madras and Mysore has a slightly higher value than the ruby variety of Bihar, known popularly as the Bengal ruby mica. The clear 1581-green mica available at Garhwal in the United Provinces shows, however, a comparatively larger value of power factor, which is even greater than that of the stained and spotted mica samples of other provinces included in the present investigation. It may be noted here that the value of power factor of clear muscovite mica of the different grades or varieties seems to be of the right order of magnitude at the frequency of our measurements. Amongst the previous investigators, Lewis, Hall and Caldwell (1931) found the spread of power factor for clear Indian ruby mica to lie between 0.01 to 0.02%. Furthermore, Dannatt and Goodall (1930) have observed that although the power factor of the green variety is about three times as large as that of the ruby at the power frequency of 60 cycles per second, they have nevertheless nearly the same value at a frequency of 800 cycles per second. This latter observation is well supported by the present data.

It is difficult to compare the power factor values of the stained and spotted micas with those reported by other investigators since the power factor is known to be very much influenced by the amount of stain or spot present in the samples under test. It is also not known whether these investigators used micas of the same localities as used in the present measurements. Very likely, they did not. It is, however, found from present data that the power factor of muscovite mica, either stained, spotted, or both, is higher than that of clear mica as has been observed by several other investigators. The sample of phlogopite mica has a still higher value of power factor.

The uses to which virgin mica is put are well known. It is used to insulate small commutator segments, condensers, heating elements and miscellaneous punched parts and washers. The grade of mica suitable for condenser insulation varies according to the service for which the condenser is designed. For D.C. and general testing and standardising purposes, mica of particularly high insulation is preferred. For every high-voltage condensers, mica of the highest electric strength must be used, while, for high-frequency condensers, low-loss mica is to be selected.

Dannatt and Goodall (1930) have found that clear ruby mica possesses outstanding superiority over the green variety inasmuch as it has not only a small power factor but also small variation of power factor and capacitance with temperature as well as small change of power factor and permitivity with frequency. These properties mark it as an almost ideal material for the insulation of precision condensers and allied apparatus. The clear green mica has also exceptionally good insulating properties. In fact it is as good as ruby mica for high-quality commercial insulating material. The only point against its use in precision condenser is that its power factor varies, as has been noted already, with frequency and probably attains a steady value only at very high frequencies.

The stained and spotted micas which have been put to test in the present measurements show that the power loss in them is not very large and, in fact, it is fairly tolerable. They are, therefore, not unsuited for use in commercial condensers of the Dubiliar types for radio purposes where great precision is not warranted. A few condensers were actually constructed with some of these mica samples and put to service where they were found satisfactory throughout the year under varying conditions of temperature and atmospheric humidity. It is hoped that more definite conclusions, regarding the uses to which the stained and spotted micas available in many parts of India could be put, may be drawn after our study of their different electrical and physical properties is complete.

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